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Organisational Design and the (dis)Integration of Human Factors in Production System Development

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For a more in-depth look on this subject, please see:

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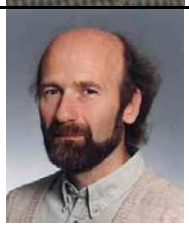

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ABSTRACT

This paper describes and generalises experiences from two cases of production system development in the Swedish context. We have observed the successful application of ergonomics to be related to the lack of coordination of human factors across groups responsible for different stages of the production system design process. This problem is magnified by the tendency for 'ergonomics' to be the responsibility of Human Resources departments who are distanced from they design process, rather than engineering teams directly engaged in design. Available tools to improve the integration of ergonomics considerations into the design process are briefly presented and discussed.

Keywords

Production system development, organisational design, management of ergonomics

INTRODUCTION

In two case studies, of the electronics and automotive sectors, we have demonstrated how decisions made early in the development process can influence both physical and psychosocial factors in the resulting workplace [1, 2]. These design decisions can be related to both strategic choices made at the onset of the project, but can also occur later in the design process as new design constraints are accommodated. The ergonomic effects on the workplace can be both positive and negative. This paper describes the production system design process in terms of a number of key stages that can influence both performance and working conditions in the resulting work system. We will attempt to isolate some of the pitfalls and opportunities related to each design stage we have observed. We argue that, since different groups are engaged at each stage of the design process, and since the influence of these groups' design choices interact to determine resulting ergonomics conditions, that control of the ergonomics consequences of the design process depends on coordination amongst these groups. We reflect on the need and opportunities available for jointly optimising human and technical system aspects in the design of profitable and sustainable production systems. We outline developmental trends observed in the Swedish context that show some potential to support efforts to integrate human and technical factors into the design process. This paper contributes to the ongoing discussion of the integration of human factors

(HF) to design [3] by focussing on an empirically determined design sequence and stakeholder groupings.

SEQUENCE OF DESIGN

Design processes are not entirely linear-rational. They are complex, contain uncertainty and non-linearity, and have powerful social and micro-political dynamics [4]. Nevertheless we generalize here a production system design sequence we have observed in the automotive and electronics sectors:

1) Product Design – specifies the assembly task, defines components, variants, and connections
2) Project Specifications - are set including physical location, project timeline, and investment level is specified creating core constraints for the design
3) Logistics system - is specified (in our cases separately from system design) and includes material supply approaches
4) Production Strategy - is chosen which specifies a specific basic flow strategy
5) Layouts - are established to feed materials and support product flow. Material handling aids are designed if deemed necessary
6) Work organization system - is chosen by the production management team as an approach to operating the given technical system

This design process can be thought of as cyclic with iterative and parallel dynamics and possible interactions between key design decisions. In our case research we have attempted to understand how decisions made at each of these 'levels' can affect ergonomics. Organisationally we note that each of these levels may be the responsibility of a different group. If ergonomic conditions in the resulting system are a combination of the efforts of all of these groups then who, in the design process, is in control of ergonomics? We argue that the isolation of HF issues to health and safety departments has contributed to the poor or absent handling of HF indicators within their own design tasks and thus simplified their own work. (Another reason may be the lack of appropriate tools and/or poor knowledge and training regarding those already available) Placing attention to ergonomics last in the design sequence means only very simple low cost changes may be implemented – the 'window of innovation' in the early conceptual stages of design has been missed.

Product Design

Product design, while not the focus of the case studies, was realised to play a critical role in defining the assembly task. Recent trends in concurrent engineering, for example make explicit and attempt to exploit the parallel execution of product and production process design [5, 6]. This produces potential for improved ergonomics by improving the design of the product itself – 'Design for assembly' (DfA) or 'Design for Manufacturability' (DfM) [7]. We have observed that product design teams are often distant from the production operations in both time and sometime geographical location. If assembly difficulties are recognised once production has started it can be very expensive to change the design of the product. Product design teams can have a substantial impact on operator ergonomics.

Project Constraints

Project constraints can influence ergonomics in a number of ways. Time is a key competitive aspect and pressure to reduce development times is intense. We have seen how this can inhibit interventions to integrate ergonomics into the design process. If ergonomics is to be integrated into the development process it may be necessary to implement these changes in the context of the organisation's

development processes – thus unburdening the design project itself. Unfortunately such an approach also delays the application of ergonomics to the next generation system. Cost constraints, a problem for us all, can also negatively affect ergonomics. It is not uncommon for technology investments to run over budget due to unexpected costs. Eliminating "ergonomic" materials or tools present areas where a budget overrun could be regained.

Basic project constraints are usually set by senior managers who are generally isolated from the ergonomics consequences of system design processes. These decisions do not affect ergonomics directly – but the constraints and performance indicators chosen set the stage for the design process. Since ergonomics is not usually part of these constraints it is no wonder that stakeholders generally avoid 'extra' attention to HF in their design work.

Logistics

The logistics and purchasing groups will generally arrange the sourcing of components and equipment and the timely delivery of these to the production system. Both of these groups tend to have a pure financial focus and may not be aware of the costly effects their choices have when items reach the shop floor. For example, the use of large crates for the delivery of parts can appear cost effective. Reaching into the bottom of these crates, however, creates high spinal loads and takes longer than when parts are more appropriately positioned. In situations where there are many product variants, and thus many part variants needed at the same location, the use of large crates may lead to much walking and carrying as operators move along a long row of component crates. This classic example shows how cost saving made in one part of the system (cost per component to the line) can lead to ergonomics and productivity deficits in another part of the system (cost of assembly). The logistics groups, and related purchasing departments currently appear to have no ergonomics tools and little recognition of how their decisions affect ergonomics.

Similarly the purchase of new equipment, made by a purchasing specialist distanced from the shop floor and the actual use of the purchased item, can be made on financial criteria without consideration to ergonomics. Awareness building and education to purchasing personnel are seen as one avenue for improvement here [8].

Production Strategy

The choice of a production strategy will determine the basic form of the resulting system. These choices will be linked to previous production models (either to continue with these or revise them) and may be specified at the corporate level in terms of a 'global model' for production. The most obvious initial choice is the selection flow strategy, for example to use a line system, is made early in the development process. In our case the 'pre-production' engineering group coordinated this choice. This selection of a basic system configuration may be made on the basis of simulation studies but may still most often be influenced by perceived industrial 'trends' or other forms of knowledge.

In our case we observed a separate group focussing on the development and implementation of a production strategy in conjunction with the management team determining the *project constraints*. The choice of system configuration interacts with the logistics strategies in determining how the material will be supplied to the system. The production strategy also seems to be tightly linked to the physical space currently available – engineers will quickly dismiss concepts that appear inconsistent with currently available space.

Workstation Layouts

The workstation layout includes final decisions for the physical arrangement of individual workstations. We have seen this design task being the responsibility of a separate engineering group (called 'production engineering' in our case) from those focusing on the production strategy and the fit of the production system into available facilities described above (performed in our case by the 'pre-production engineering' group). This can include the division of labour as specific parts are assigned to specific stations (e.g. line balancing) and are generally performed within constraints established by the general production strategy and the packaging constraints determined by the logistics group. The location of tools and position of component crates relative to the operator and product are determined by this group. We have observed that the amplitudes of operators' physical loading exposures are determined at this stage as the layout determines required working postures as well as the forces required to acquire and assembly parts. If certain loads are seen as too demanding for operators it is at this stage that lift assists or other devices might be developed to reduce load amplitude.

Work Organisation

While the work organisation may be considered during the design process this feature is often seen as independent of the technical design of the system. In the cases we observed it was the production management who were responsible for the choice of a particular work organisation. At this level decisions may include weather or not to use 'teams' and how exactly these teams are to work together. Job rotation schedules, operator training routines and the extent to which operators are engaged in developing their production systems are all the responsibility of the 'work organisation' group. Choices here appear to both modify physical load and influence psychosocial conditions.

THE PROBLEM OF DISINTEGRATED DESIGN

We have attempted to illustrate how different groups engaged in the design process all influence ergonomics in the resulting system. In some cases the decisions are cumulative or interacting. In the face of multiple stakeholders, who each influence some part of the ergonomics in the resulting production system, one can ask: Who is in control of ergonomics? The answer to this question depends on the extent to which the influence of these different stakeholders can be coordinated in order to achieve an optimal result. It is a common 'systems' effect that communication barriers between groups can lead to dysfunctional effects and sub-optimal performance in the system as a whole [9]. While ergonomics tends to be positioned within HR the real influence over system design lies with engineering groups who often lack knowledge, tools and mandates to create systems with good ergonomics.

Typically the ergonomics community complains it is engaged too late in the design process to affect anything but the simplest of layout changes [3, 10]. These may influence perhaps load amplitudes but rarely affect the pattern or duration of loading. If there is no attempt to coordinate the decisions made by the various design teams then it is unlikely that globally optimal systems will result. This disintegration problem can be aggravated by the perceptions of some groups that 'ergonomics' is not their domain and thus does not need to be attended to in their design work. Thus we see the need for tools and processes that can support an integrated consideration of HF in design that can lead to globally optimal design solutions.

APPROACHES TO INTEGRATION

In this section we identify and discuss a number of integrative approaches we have observed in our 2 case studies as well as in the literature that appear to show potential for improved ergonomics and system performance.

PROJECT MANAGEMENT

Design project management itself poses one of the most obvious avenue for integrating ergonomics conditions into the design project management process. If the design project is managed by a formal system, such as a 'gate' system [11], then ergonomics tools can be mandated at each stage of the development process. This option is now realised in one of our investigated cases. We plan to follow this trial and later report on this. This requires establishing formal process, connected to project constraints, by which the team responsible for each development stage can demonstrate compliance with existing standards and procedures with regards to HF. The effectiveness of such an approach will depend on how well the tools used within each stage serve to improve ergonomics. Establishing measurable objectives that are compatible with designers' processes sometimes proves to be a challenge. Wulff et al. [12] have described in some details the problems designers can face in dealing with such guidelines. If checks and controls are not built into the design control system (as per point 1) then establishing HF objectives alone will not guarantee success. Munck-Ullsfält has described an approach using a series of checklists adapted to the design process that ensures the application of ergonomics considerations at each stage of the design process [13]. Such approaches appear promising as they both accommodate the design process and facilitate communications between experts in different design knowledge domains.

AUTOMATION

Automation is often seen as an ergonomics advantage as it tends to focus on the removal of repetitive monotonous work. Indeed, in one implementation of electronic components insertion we saw a drastic reduction in the system-wide amount of repetitive getting and putting movements. We also observed the creation of new machine monitoring work with variable tasks and movement variety. For the few remaining manual assembly stations, however, repetitiousness had increased and, in interaction with the implementation of an automatic conveyor system, the variety of work tasks was reduced to almost exclusively getting and putting motions interspersed with short periods of forced waiting for the line system [2]. The ergonomic impact of automation therefore will depend on both the conditions for operators attending to the new machinery, as well as the conditions for operators responsible for the remaining manual production work.

FLOW SIMULATION

Flow Simulation, or discreet event simulation, is becoming more common in production planning. While this, like all simulation, can suffer from the 'garbage in – garbage out' problem we see flow simulation as having great potential for the consideration of ergonomics that is not yet generally recognised. The flow simulation can provide insights into the time demands of work and even to work-wait patterns in a particular model [14]. In terms of performance the simulation can test the effects human variability on system output for different flow approaches. In this conference we present another paper describing how flow simulation allows the testing different layouts sensitivity to human factors such as the presence of a worker with reduced work capacity (due perhaps to injury, age, or lack of experience) as well as the possibility to give operators some control over their break schedule [15]. We argue at this conference that, by allowing operators some control over their work schedules, one can test the sensitivity of specific work organisations and flows to increased operator job control – a known psychosocial risk factor for ill health outcomes. Such models, if combined with human

simulations which could quantify loading for particular activities, would allow for a comprehensive assessment of physical loading under a variety of system configurations and operating conditions.

HUMAN SIMULATIONS

There is growing awareness of the utility of mannequin simulation programs for the evaluation of working postures during workstation design. Human simulation can be easier to use if these models can provide information directly comparable to company standards. This creates an unambiguous result allowing compliance to be demonstrated. A popular approach in such measurement systems appears to be the presentation of results in simple red, yellow, green colour coding. It seems that, while quantified systems are being used – a simple classification is all that is currently desired by design teams.

Sophisticated 3D modelling allow designers to examine reach and fit, movement path, and line of sight aspects along with mechanical loading aspects. Sundin [16, 17] has described extensively the use of such computer mannequin software to support ergonomics in the product design process. Such 'participatory design' approaches can complement participatory ergonomics.

PREDETERMINED MOTION TIME STUDIES

Predetermined motion time studies (PMTS) provide information on 'standard' times operators will require for specific work operations such as getting, walking, fastning etc.. PMTS are commonly used by engineers attempting to distribute work evenly, according to how much time is needed at each station, amongst a series of stations. This, in effect, determines the duration of exposure to different tasks an operator at a particular station will experience. Examples of such tools include MTM, MOST, and in Sweden, SAM. Ergonomics extensions to these tools have been constructed that permit inclusion of physical load information in these analyses. ErgoSAM is one example of such a tool [18], which permits the production engineer to consider both the balance of both physical loading and time when dividing work between different workstations.

ERGONOMIC VALUE STREAM MAPPING

To directly connect ergonomics to production system development, an Ergonomic Value Stream Mapping tool (ErgoVSM) [19] has been developed. The aim is to support higher efficiency, better work environment and a sustainable working life. The tool is built on an existing engineering tool, Value Stream Mapping (VSM), a rationalization tool frequently used in industry according to Lean Production principles. VSM is supplemented by ergonomic assessments based on available ergonomic methods and new approaches where appropriate. It can be used by practitioners with minimal initial help from experts. Drafts of the ErgoVSM have been tested in industrial companies with positive responses.

The methods that have been developed (mostly by the ergonomics community) provide potential for the integration of ergonomics into workplace design problems. Weather or not these approaches are taken up and applied remains a management issue. A further challenge to companies includes linking their ergonomics efforts to their strategic practice so as to reap maximum benefit from their HF efforts. This involves moving beyond a 'problem filter' approach to identifying only health related ergonomics risks – but also working actively to see that employees are able to contribute maximally to helping the company reach it's organisational goals. The connections between ergonomics and company strategy are presented and discussed elsewhere in this conference [20, 21].

CONCLUSIONS

In Swedish manufacturing industry HF are generally not considered in the design of the development organization and are thus poorly coordinated in the design process. While tools appear to be coming available to foster integrated consideration of HF and performance, the uptake of these tools remains a concern. Tool utilization may also hinge on available knowledge and training for affected stakeholders. Awareness of the ability of ergonomics to contribute to broader organizational goals (beyond just health) may also support integration efforts. Tools focused on supporting each developmental stage may not capture problems related to the interaction of design elements at different stages – good coordination mechanisms are also needed.

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The Institute has operations in several locations in Sweden

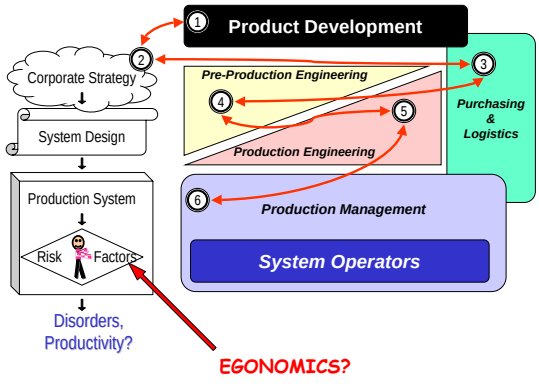
Discussion from 2 Cases Studies

1. Electronics Assembly
2. Engine Assembly

- generalisation from case series studies…
- Swedish context
- Seeking entry points for ergonomics in design

Design Process Stages:

1. Product Design
2. System Specifications & Constraints
3. Logistics System
4. Flow Strategy & Concept (Line vs. Cells)
5. Workstation Balance & Layouts
6. Work Organisation



Flow Strategy & Work Organisation → Pattern of loading & psychosocial

- Line production associated with low job control

Logistics System + Layout → Load Amplitude

Problems / Challenges

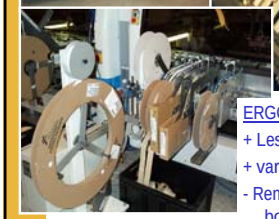
- Design is not linear-rationale!
- 'Stages' interact & overlap
- Stakeholders' interests & goals differ!
- HF is not coordinated across the process
- risk is an *emergent feature* of design

NEED TO INTEGRATE HUMAN FACTORS IN DESIGN!

Project Management

'Gate' systems used to track use of ergo tools – including FMEA, DfA, or other risk analysis tools Throughout the development process

Automation



- Less manual work
- save 2.6 min / board
- •+ machine supervision
- •++ Workstation cost

ERGONOMICS

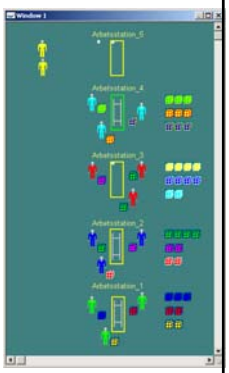
+ Less time stereotyped tasks

+ variable supervision work (reaching?)

- Remaining assembly work was tightly bound to system & even more repetitive

Flow Simulation

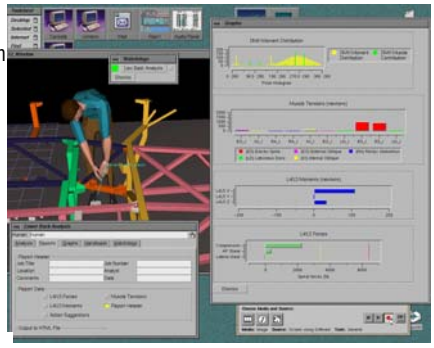
- Can test alternative production strategies
- Potential to include consideration of human factors (physical & psychosocial
- Next step is to integrate with human simulations



Human Simulation (no human required!)

- HumanSim
- Jack
- WATBAK
- 3DSSP
- Etc.

- ~DfA?



Sundin 2000, IEA

Pre-Determined Motion Time Studies

- MTM, MOST, SAM used to balance work time for given set of tasks
- ErgoMOST, ErgoSAM – ergonomic add-ons to traditional PMTS establishing ergonomics scores for each balance

Value Stream Mapping

- A common 'lean' work-tool
- ErgoVSM adding ergonomics component to existing engineering tools

Conclusions?

- Tools being adopted to support most phases of development
- Logistics notably unaffected
- VM tools may simply re-enforce communication barriers in the process
- VM tools carry *potential* for integrated consideration of ergonomics – tech & social barriers

Q: What supports / assists this integration?